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Historical Aspects of Hyperbaric Physiology and Medicine

Chandrasekhar Krishnamurti

Abstract

The history of hyperbaric oxygen therapy (HBOT) makes for fascinating reading. From pneumatic chambers and compressed air baths to empirical therapeutic applications during the nineteenth century, the impetus to scientific application of HBOT began in seeking solution for decompression sickness during various construction ventures. French physiologist Paul Bert's research was pathbreaking and provided a scientific explanation on the etiology of the "bends." In 1908, JS Haldane's experiments recommended staged decompression and made diving safe. In 1921, OJ Cunningham employed HBOT to treat hypoxia secondary to lung infections successfully. It was cardiac surgeon Ite Boerema who put HBOT on a solid footing with his open-heart surgery results in various pediatric cardiac conditions and rightly deserved the title of father of modern-day hyperbaric medicine. From 1937 onwards, HBOT research snowballed into treating a wide variety of diseases. In 1999, the Undersea and Hyperbaric Medical Society and Food and Drug Administration recognized the value of HBOT, and this led to its becoming a major tool in the armamentarium of clinicians, either as a primary or adjunctive therapy for a spectrum of diseases.

Keywords: history, hyperbaric oxygen therapy

1. Introduction

Since 4500 BC, breath-holding dives for mother-of-pearl, sea sponges, and coral was a distinct occupation. These free divers could hold their breath for extended periods of time, and their work was confined to waters less than 30 m (100 ft) deep. It was undoubtedly a hazardous occupation, and many of them succumbed to decompression sickness after rapid surfacing. Persian king Xerxes the Great (520–465 BC) employed divers to salvage sunken goods and treasures from the wrecks of Greek ships he had sunk in numerous battles at sea. Some of these dives were recorded to depths of 20–30 m and lasting 4 minutes at a time. The ancient Greek historians Herodotos and Pausanias wrote about a Greek hero named Scyllias from Scione, who used a reed and diving capsule made from animal skins to cut the mooring lines of enemy ships. Pausanias even taught his own daughter Hydna to dive. Alexander the Great (365–323 BC), under the advice of a reputed astronomer named Ethicus, dived into the Bosphorus straits in a bathysphere, accompanied by a dog, a cat, and a rooster, after entrusting the security of the hoisting chain to his most loyal mistress. Taking advantage of the moment, she chose to elope with her lover after casting the chain into the sea, abandoning Alexander and leaving him to figure out his escape on his own! In 300 BC, Aristotle described the ruptured eardrum as a complication of undersea diving.

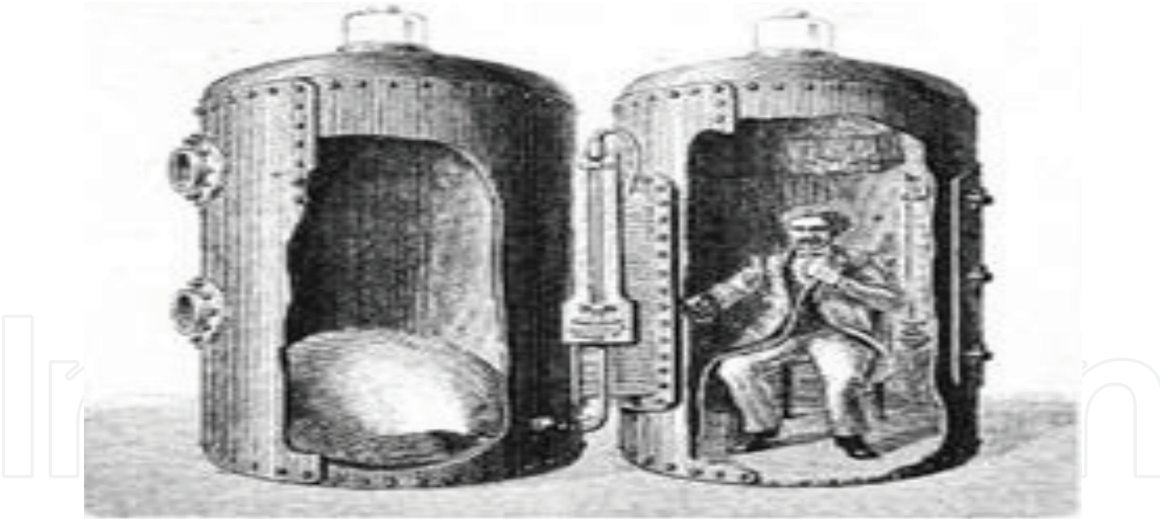


Figure 1.
Henshaw and his domicilium.

While living in Venice in the late fifteenth century, Leonardo da Vinci designed diving suits to enable divers cut holes in the hulls of invading ships, but none seem to have been developed or used [1].

In 1620, Dutch inventor Cornelis Jacobszoon Drebbel (1572–1633) designed a wooden diving boat, sealed against water by greased leather, to travel in the River Thames at a depth of around 4 m, from Westminster to Greenwich. Air was supplied by two tubes with floats to maintain one end above water [2]. In sixteenth century England and France, full diving suits made of leather were used to depths of 60 ft with air being pumped down from the surface with the aid of manual pumps.

The first documented use of hyperbaric therapy was in 1662, when a British clergyman and physician named Nathaniel Henshaw used a system of organ bellows with unidirectional valves to change the atmospheric pressure in a sealed chamber called a domicilium (**Figure 1**). Without any scientific rationale whatsoever, Henshaw claimed that high air pressures would remedy acute conditions while lower pressures would yield salutary results in chronic disorders. His domicilium therapy was touted to improve digestion and prevent lung diseases by manipulating ambient pressures without increasing oxygen concentrations, as oxygen was not discovered until nearly a century later [2].

In 1690, Edmond Halley designed a diving bell ventilated with weighted barrels of air sent down from the surface. Employing this device, Halley, escorted by five of his close friends, undertook a dive to a depth of 60 ft in the River Thames in that bell and remained submerged at that depth for 90 minutes. Too heavy for salvage work, Halley made improvements to his bell, extending his underwater exposure time to over 4 hours. The first deep-sea diving suit was invented in 1819 by Augustus Siebe. It used compressed air supplied to the helmet for ease of movement underwater.

All of these early submersibles used ambient air and were called “pneumatic chambers” or “compressed air baths.”

2. The era of empirical HBOT/HBO spas

Nearly two centuries later, in the 1830s, there was a rebirth of interest in hyperbaric medicine in France. In 1834, the French physician Junod built a hyperbaric chamber designed by the steam engine inventor James Watt, who was well-versed in pressure physics. This appliance could generate a maximum of 4 atmospheres pressure and used to treat pulmonary afflictions using pressures

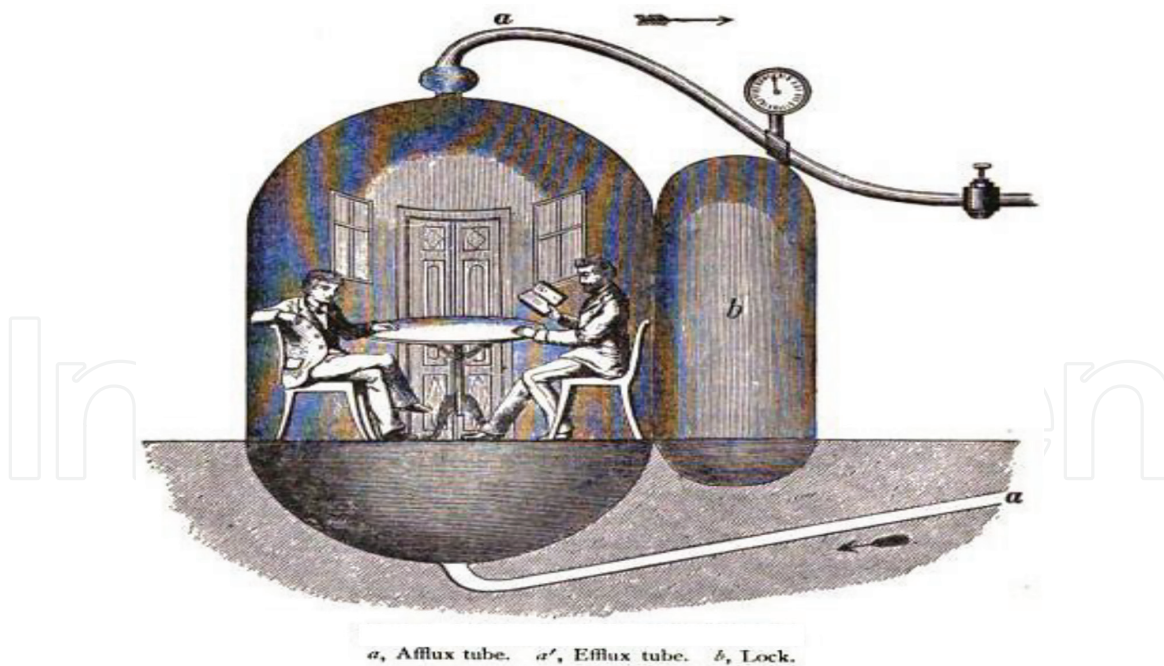


Figure 2.
 Taberie's pneumatic chamber.

between 2 and 4 ATA. Junod referred to his treatment as “Le Bain d’air comprimé” (the compressed air bath), and claimed that it increased circulation to the internal organs and the brain, resulting in feelings of well-being and better general health.

Taberie designed a spherical pneumatic chamber made of cast iron with two pipes, one to provide pressure from a hydraulic compressor run by steam and the other to allow for ventilation. Carpet covered the floor to conceal the pipes, and it featured an antechamber to allow the physician to enter and exit without disturbing the pressure. The passage was also used to stock books, newspapers, and drinks for the patients (**Figure 2**).

Lange had a cylindrical chamber constructed out of wrought iron, designed to accommodate four persons. The temperature of the compressed air within the chamber was lowered in two ways. The first employed a stream of cold water directed against the force pump and the supply pipes. The second method was by filling a cup-shaped space at the top of the chamber with cold water and allowing it to cascade down the sides to soak sheets of linen and cool the air by evaporation. In winter the chamber was kept at a comfortable temperature by heating. The chamber was also provided with a device for regulating the flow of the incoming air so that it entered in a steady stream (instead of a succession of puffs in earlier versions) by a force pump. The pressure was secured, as in Tabarie’s system, by regulating the inflow and outflow of the air (**Figure 3**).

Leibig’s pneumatic chamber was located at Dianabad in Reichenhall, Bavaria, Germany. This pneumatic chamber had three chambers, each one capable of accommodating three persons. One antechamber connected all three rooms, allowing the physician to enter and exit without affecting the ambient pressure. The antechamber also acted as a large pressure regulator, preventing the patients from being affected by sudden surges of pressure. A ventilation pipe through an opening in the ceiling provided good ventilation (**Figure 4**). The temperature and pressures within each chamber could also be individually controlled [3].

In 1837, Pravaz built the largest hyperbaric chamber in Lyon, France, to seat 12 patients and treat patients with pulmonary conditions including tuberculosis, laryngitis, tracheitis, and pertussis, as well as unrelated conditions such as cholera,

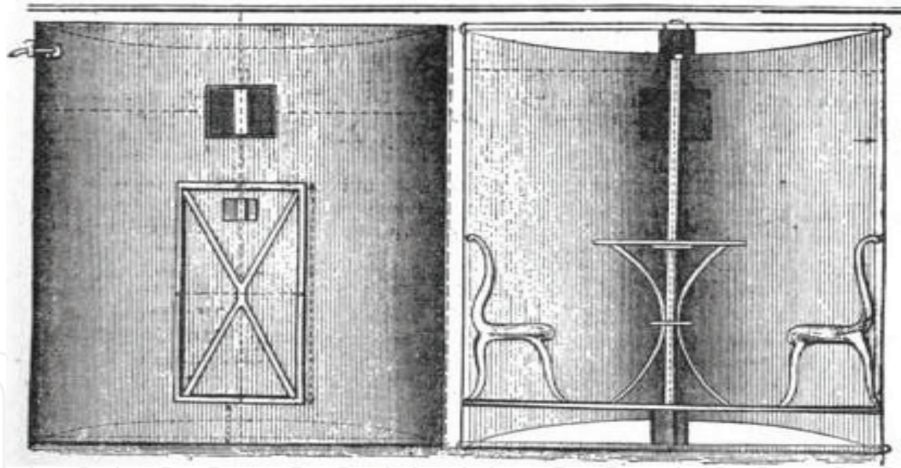


Figure 3.
Lange's pneumatic chamber.

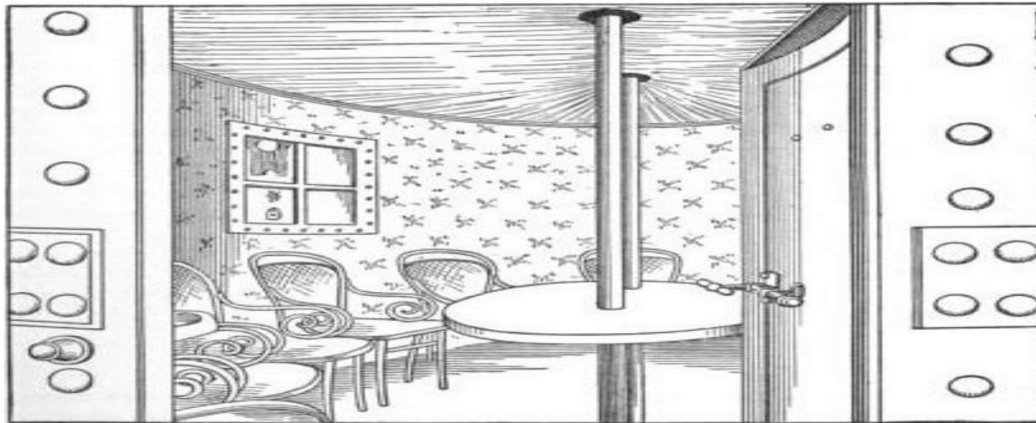


Figure 4.
Leibig's pneumatic chamber.

conjunctivitis, deafness, menorrhagia, and rickets. In 1855, Bertin wrote a book on compressed air therapy and even constructed his own hyperbaric chamber.

Compressed air therapy was first introduced into the USA by JL Corning in 1871. In 1876, Kelly treated a patient in a "Compressed Air Bath Apparatus" having two locking plates operated from outside to seal pressures. In 1877, French surgeon Fontaine developed the first mobile hyperbaric operating theater. The high ambient pressure was claimed to facilitate the reduction of hernias and provide relief for patients with lung diseases. Over the next 3 months, 27 surgeries were successfully performed within this mobile hyperbaric chamber (**Figure 5**). Spurred by the results, Fontaine ventured to erect a mammoth hyperbaric surgical amphitheater to accommodate 300 patients in one sitting. This did not see the light of day as Fontaine died from an accident at the Pneumatic Institute to become the first physician to be martyred in the history of hyperbaric medicine [4].

In 1885, C Theodore Williams published his "Lectures on the Compressed Air Bath and its Uses in the Treatment of Disease" in the *British Medical Journal*, extolling the use of atmospheric air under different degrees of atmospheric pressure to treat diseases. He remarked that this mode of therapy was among the most important advances in modern medicine and expressed astonishment at its being ignored in England [5].

Back in the USA, during the closing days of the World War I, Kansas-bavsed physician Orval J Cunningham built a hyperbaric chamber in 1921 at Lawrence, Kansas. He used the facility to treat victims of the Spanish influenza epidemic that

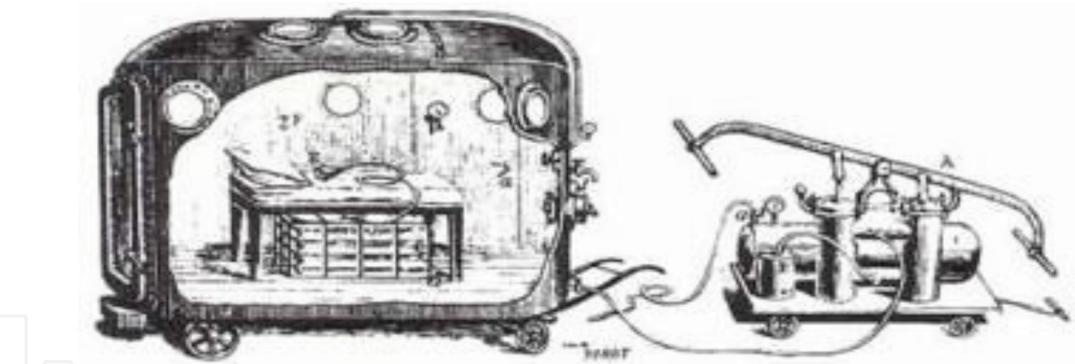


Figure 5.
Fontaine's mobile hyperbaric operation theater.

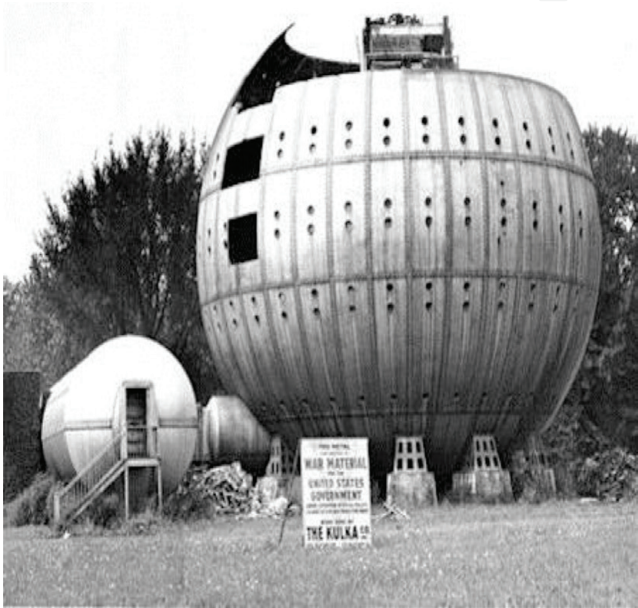


Figure 6.
Cunningham's hyperbaric hotel—outside and inside view.

swept North America. Noticing that people in the valley fared better than those living in the mountains, Cunningham theorized that atmospheric pressure or barometric factors were responsible for the higher mortality rates in those residing at higher elevations. He observed remarkable improvements in patients treated with HBO, especially those who were cyanotic and comatose. In 1923, heat from open gas burners warming the chambers in winter scorched the insulation and started a fire, but all patients were safely evacuated. In another incident, a mechanical failure caused a complete loss of pressure within the chamber and all patients died. This did not, however, deter Cunningham's enthusiasm for hyperbaric air. He went on to treat diseases such as syphilis, hypertension, diabetes mellitus, and cancer, believing that anaerobic infections played a role in the etiology of all these afflictions. In 1928, with the financial backing of Henry H. Timken, a roller bearing manufacturer and tycoon, Cunningham built the largest hyperbaric chamber in the world along the shores of Lake Erie in Cleveland, Ohio, at a cost of 1 million dollars. This "Steel Ball Hospital" or "Cunningham's Sanitarium" was a five-story high steel sphere, 64 ft in diameter with 60 rooms and weighing 900 tons. Each floor of this structure had 12 rooms, with all the amenities of a good hotel (**Figures 6 and 7**). The growing popularity of Cunningham's treatments prompted the Bureau of Investigation of the American Medical Association (AMA) to request the doctor to validate his claims



Figure 7.
Cunningham's hyperbaric hotel—exterior and interior views.

regarding the effectiveness of hyperbaric therapy. Cunningham refused to share the details or cooperate with the AMA, leading to his being labeled a quack and a fraud. The chamber was dismantled in 1937 and sold for scrap during World War II [6].

3. A historical account of decompression sickness and its treatment

In 1840, Charles Pasley, charged with the recovery of the sunken warship HMS Royal George, commented that, of those who made frequent dives, “not a man escaped the repeated attacks of rheumatism and cold.” In 1841, Trigger, a French mining engineer, used a pressure chamber to deliver workers to the bottom of the river to extract coal. In 1845, he reported that some of his miners complained of joint pains and nervous disorders after surfacing. The first recorded death from “caisson disease” (which later came to be known as decompression illness (DCI) or acute decompression sickness) occurred in 1859 during the building of the Royal Albert Bridge, a railway bridge in England spanning the River Tamar from Saltash to Plymouth. Several workers were taken ill after emerging from deep underground after long hours of work under high atmospheric pressure conditions. In 1871, during the construction of the Eads Bridge in St. Louis, 352 compressed air workers, including Alphonse Jaminet, the physician in charge, were employed. Thirty workers developed serious conditions with 12 ending fatally. Jaminet himself suffered decompression sickness, and his personal description was the first such recorded. It was in 1873 that Andrew Smith first utilized the term “caisson disease” to describe 110 cases of decompression sickness that occurred during construction of the Brooklyn Bridge. The project employed 600 compressed air workers, and recompression treatment was not available on site. In 1882, during the Hudson tunnel construction in New York, every fourth worker died of bends until a recompression chamber was installed to treat the condition. Only three workers died of bends over the next 18 months.

Paul Bert, a French professor of physiology and a student of Claude Bernard, is considered the father of pressure physiology (**Figure 8**). In 1878, while working closely with Dr. Alphonse Gal, the first doctor to actually dive in order to study



Figure 8.
Dr. Paul Bert (1883–1886).

how the body reacted underwater, Bert studied Gal's reports on divers who became symptomatic or died while surfacing. He conducted a series of dog experiments, exposing them to 7–9¾ atmospheres and subjecting them to rapid decompression. A majority of them died and exhibited grossly distended bodies with their right heart chambers filled with gas. When decompression was done at slowly over 1–2 hours after exposure to similar pressures, none of the dogs succumbed. Applying Dalton's and Henry's gas laws, Bert concluded that too rapid a decompression induced a pathophysiologic insult secondary to supersaturation of body tissues with nitrogen, causing the formation of nitrogen bubbles. He also went on to suggest that divers stop halfway to the surface to allow for slow decompression after a deep dive—what is now known as deep stops. Bert was also the first to describe oxygen toxicity at pressures in excess of 1.75 ATA. This adverse effect on the central nervous system came to be known as the “Paul Bert effect” [7, 8].

In 1908, Scottish physiologist John Scott Haldane conducted experiments at the Lister Institute of Preventive Medicine in London assisted by Lieutenant Guybon Damant of the Royal Navy, an expert diver and amateur scientist, and a physiologist Edwin Arthur Boycott. A herd of 85 goats was assembled, and the researchers put groups of up to eight goats inside compression chambers for specific periods of time. Pressures were then normalized before releasing the animals into the institute's yard for observation. These studies confirmed that those goats decompressed by stages did not exhibit signs of the bends (**Figure 9**). Haldane then introduced the concept of half times—the time required for a particular tissue to become half saturated with a gas—and recommended staged decompression, especially at shallower depths. He prepared detailed practical dive tables for the Royal Navy to prevent acute decompression sickness. These guidelines remained the foundation of all diving operations until 1956 [10]. Heinrich Dräger was the first to explore the use of pressurized oxygen in decompression sickness (**Figure 10**). His protocols were put into practice by Behnke and Shaw, who used HBOT for treating decompression sickness in the late 1930s. They replaced oxygen in place of compressed air, and their work resulted in the use of the first nitrogen-oxygen mixtures and hyperbaric treatment being tailored to the severity of the injury [11]. In 1939, the US Navy began treating divers suffering decompression sickness with hyperbaric oxygen therapy. After World War II, the US military conducted extensive research in HBOT, and this expanded the existing knowledge about survivable pressures and popularized HBOT in the late 1950s and early 1960s. In the 1980s, Paul Harch began an in-depth study of brain decompression illness (DCI) and evaluated divers with this disorder. He concluded that it was not residual gas that was being treated but ischemic brain injury. He

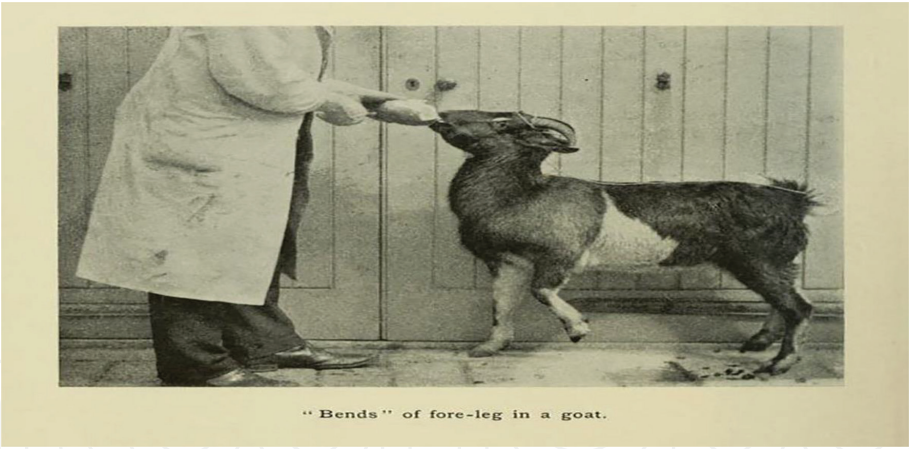


Figure 9.
Bends in the foreleg of a goat after experiments performed by physiologist Haldane [9].

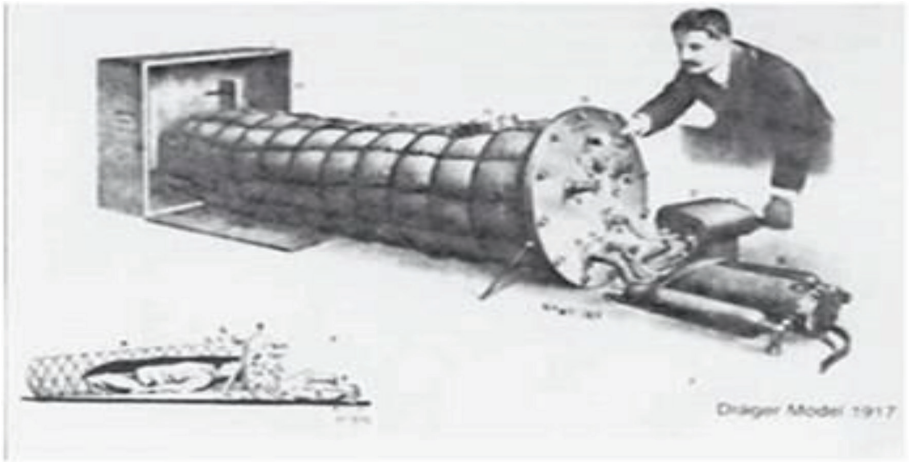


Figure 10.
Dräger and his recompression chamber.

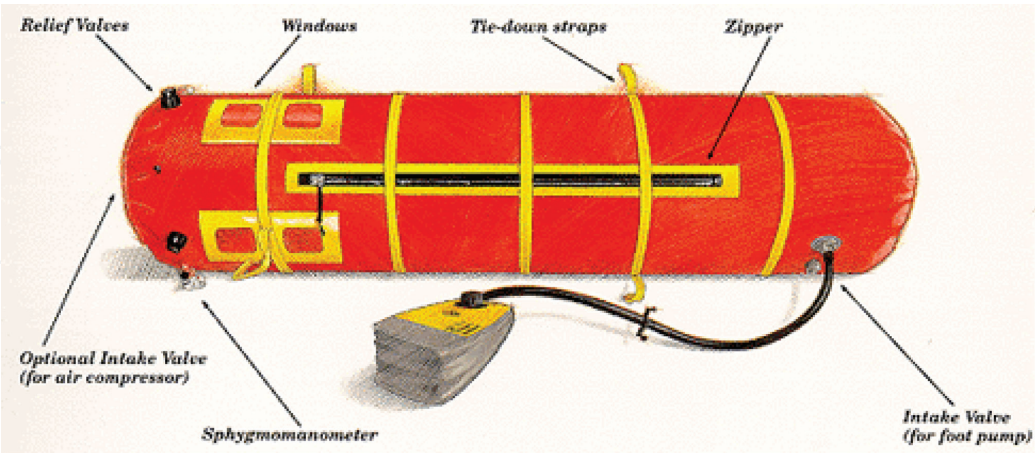


Figure 11.
The Gamow Bag.

went on to develop individualized treatment protocols for over 50 different chronic neurological disorders. Harch is considered to be the foremost authority in the use of HBOT and SPECT brain blood flow imaging in neurology [12–14]. In 1990, former microbiology professor Igor Gamow invented and patented the Gamow Bag that provided mountaineers with a mobile and effective method to treat high-altitude sickness. This bag is a single-place portable hyperbaric chamber, pressurized with a

foot pump, to simulate a descent to 7000 ft (**Figure 11**). In 1992, Harch treated the first delayed decompression sickness, which led to the treating of “dementia pugilistica” in boxers and cerebral palsy and autism in children [15].

4. Treating diseases with HBO

In 1937, Brazilians Ozorio de Almeida and Costa pioneered the use of HBOT in treating leprosy [16]. In the 1950s, Ite Boerema, a cardiac surgeon from the Netherlands, conceived the idea of “flooding” the body’s tissues with extra oxygen. Working with the help of the Royal Dutch Navy, Boerema conducted a series of animal experiments and operations within a hyperbaric oxygen chamber (**Figure 12**). These went off without a hitch and led to the installation of a large operating hyperbaric chamber at the University of Amsterdam. Many children with congenital heart diseases like tetralogy of Fallot, transposition of great vessels, and pulmonic stenosis were operated in this facility with great success. Boerema mooted the concept of “Life without blood” using HBO, when dissolved oxygen sufficed to meet the entire body’s oxygen needs without the need for red cells or hemoglobin. Boerema is credited with being the father of modern-day hyperbaric medicine [17].

In 1955–1956, I Churchill-Davidson evaluated clinical trials on HBOT as a potentiator for radiation therapy in cancer patients at St. Thomas Hospital in London [18]. Public interest in hyperbaric oxygen therapy started to grow in the 1960s after publicity about its use in treating President John F Kennedy’s sick infant. In 1961, a colleague of Boerema, W. H. Brummelkamp, published a paper on inhibition of anaerobic infections by HBOT [19]. In 1962, Smith and Sharp reported the enormous benefits of HBO in carbon monoxide poisoning. They recommended that all those having a verified carboxyhemoglobin level above 25% needed immediate HBOT at 3 ATA for 90 minutes, followed by two or three more sessions for full recovery, making HBO very cost-effective [20]. Global interest in HBOT was rekindled by this finding, resulting in hyperbaric units being installed at many centers like Duke University, New York Mount Sinai Hospital, Presbyterian Hospital and Edgeworth Hospital in Chicago, Good Samaritan in Los Angeles, St. Barnabas Hospital in New Jersey, Harvard Children’s Hospital, and St. Luke’s Hospital in Milwaukee. In 1965, Perrins from the UK demonstrated the effectiveness of HBOT



Figure 12.
Dr. Boerema with children operated by him.

in osteomyelitis [21]. In 1966, Saltzman and coworkers from the USA proved the effectiveness of HBOT in stroke patients [22].

In 1970, Boschetty and Cernoch of Czechoslovakia conducted a trial of HBOT for multiple sclerosis. In their series 15 out of 26 patients with multiple sclerosis showed improvement after HBOT at 2 atmospheres [23]. In 1971, Lamm of West Germany used HBOT for treatment of sudden deafness. It was shown that HBOT shortens the course of healing in high-pitch perception dysacusis by upregulating constitutive nitric oxide synthase in the substructure of the cochlea [24]. In 1973, Thurston pioneered studies that showed lower mortality figures in patients with myocardial infarction treated with HBO. HBOT was shown to improve oxygen supply to the threatened heart and reduce the volume of infarct size and other major adverse outcomes [25]. In 1972, Richard A Neubauer set up the Ocean Hyperbaric Neurologic Center in Lauderdale-by-the-Sea exclusively for HBOT in the management of various central nervous system disorders. He mooted the concept of “idling” neurons capable of surviving for years or even decades after the original injury. He claimed that these injured neurons could be re-activated with HBOT and that the greater the number of idling neurons, the better would be the patient’s response to HBOT [26]. Neubauer was also the co-founder and executive director of the American College of Hyperbaric Medicine. After his death in 2007 at the age of 83, his clinical research center in Florida was renamed the Neubauer Hyperbaric Neurologic Center. In 1976, Hollbach and Wasserman determined that 1.5 ATA (atmospheres absolute) maximizes oxygen content and glucose metabolism in the brain [27].

In 1985, RE Marx and his colleagues observed that the rate of osteoradionecrosis was 30%/patient in patients treated with penicillin alone while rates in those treated with HBO was only 5% [28]. In 1987, Jain successfully treated patients with paralytic stroke using HBOT [29, 30]. In 2002, a US Army study confirmed that HBOT repairs white matter damage in children with cerebral palsy. In 2005, Stoller of the USA treated the first case of a child with fetal alcohol syndrome using HBOT and with good outcome [31]. In 2006, Thom of the USA discovered that HBO causes stem cell mobilization [32]. In 2010, Godman discovered that HBOT activated 8101 genes, resulting in reduction of inflammation and increase in growth in body tissues [33, 34]. In 2011, Stoller treated the first retired National Football League (NFL) player for chronic traumatic encephalopathy [35]. In 2012, Harch and his colleagues demonstrated that blast-induced post-concussion syndrome and post-traumatic stress disorders responded to HBOT [15].

Air or gas embolism
Carbon monoxide poisoning; cyanide poisoning; smoke inhalation
Clostridial myositis and myonecrosis (gas gangrene)
Crush injuries, compartment syndromes, and other acute traumatic peripheral ischemias
Decompression sickness
Enhancement of healing in selected problem wounds
Exceptional blood loss anemia
Intracranial abscess
Necrotizing soft tissue infections
Refractory osteomyelitis
Skin flaps and grafts (compromised)
Delayed radiation injury (soft tissue and bony necrosis)
Thermal burns

Table 1.
UHMS- and FDA-approved indications for hyperbaric oxygen therapy.

The UHMS and FDA approved HBOT for treatment of conditions like autism, stroke, air embolism, ischemic limbs, split-thickness skin graft acceptance, failed grafts, flap survival and salvage, wound reepithelialization, acute thermal burns, etc. (**Table 1**) [36, 37].

Many patients do not respond to aggressive acid-suppressing medications. HBOT has a beneficial effect in patients with blunt duodenal trauma, duodenal ulcers, and indomethacin-/radiation-induced gastritis. This salubrious effect is mediated by decreased production of oxidative stress markers like tumor necrosis factor-alpha, interleukin-1beta, neopterin, myeloperoxidase, and malondialdehyde. HBOT is seen to improve the acid-neutralizing function of the stomach, normalize gastric motility, reduce the duodenum acidification, decrease edema, and improve the blood flow both in human and equine studies [38, 39]. These effects were also seen in cases of inflammatory bowel diseases like Crohn's [40].

5. Landmark academic events in HBOT

In September 1961, the First International Congress on the clinical applications of hyperbaric oxygen was held in Amsterdam. The Second International Conference on HBO was held in Glasgow in September 1964, with detailed deliberations on various aspects of HBOT. In November 1965, the Third International Congress on HBOT was organized at the Duke University at Durham, North Carolina. The Fourth and Fifth International Congresses were held in Sapporo, Japan, and Vancouver, respectively, in 1969 and 1973. The University of Aberdeen, Scotland, hosted the sixth conference in August 1977. The subsequent International Congress was held in Moscow in 1981 and is an annual event thereafter. The deliberations during these academic forums threw fresh light on the basic physiology, oxygen toxicity, and therapeutic applications of HBO in human disease.

The Undersea Medical Society (it added hyperbaric to its name in 1986), an organization made up largely of naval and ex-navy physicians, was founded in 1967 in the USA. It reviewed the indiscriminate and inappropriate use of the HBO chamber for a variety of medical conditions by practitioners searching for a "cure-all" therapy, tarnishing the credibility of hyperbaric medicine. This non-profit organization, now known as the Undersea and Hyperbaric Medical Society (UHMS), set up a Committee on Hyperbaric Oxygen Therapy in the 1970s to systematically review all the available scientific evidence for HBOT and formulate absolute indications for HBOT. This was accepted by insurance providers, including Medicare. The UHMS is committed to providing, promoting, developing, and raising the quality of care across the spectrum in scientific communication, life sciences, and clinical practices of hyperbaric medicine by promoting high standards of patient care and operational safety. It offers accreditation and certificate of competency and credibility and has over 2500 members in 50 countries. UHMS also awards board certification in Undersea and Hyperbaric Medicine through the American Board of Emergency Medicine (ABEM), the American Board of Preventive Medicine (ABPM), and fellowship training in Undersea and Hyperbaric Medicine.

In 1980, Dr. Richard A. Neubauer and Dr. William S. Maxfield formed the American College of Hyperbaric Medicine (ACHM) to foster the ethical advancement and expansion of hyperbaric medicine. The International Society of Hyperbaric Medicine was founded in 1988.

Hyperbaric medicine was approved by the American Board of Medical Specialties as a sub-specialty of emergency and preventative medicine in 2000.

6. Developments in HBOT chambers

In 1860, the first hyperbaric chamber in the North American continent was constructed in Oshawa, Ontario, Canada. A year later, a neurologist, James Leonard Corning, built the first hyperbaric chamber in the USA in New York. This chamber was used to treat “nervous and related disorders.” The first decompression chamber was invented by the Italian engineer Alberto Gianni in 1916 [39, 40]. In 1928, the Harvard Medical School built a hyperbaric chamber for medical research. Among the largest HBOT chambers is the 22 ton 32 ft wide 14 ft wide one at the Utah Valley Regional Medical Center, USA.

In modern times, many traditional hard-shell hyperbaric chambers and soft-shell, portable hyperbaric chambers (**Figure 13–18**) are manufactured by several companies and available in every major city. The latest chambers must comply with NFPA-992012 Edition Chapter 14 Code in the USA and European 1997 CEN pressure vessels 97/23E standards as well as the 1998 ECHM recommendations for safety. The newer chambers feature hingeless pressure-sealed doors, antifric-tion bearings, antibacterial leather upholstery, and high-quality resin fiber loop mattresses and pillows that dissipate heat and moisture generated by the body during therapy. The newer low-pressure monoplace chambers are portable and

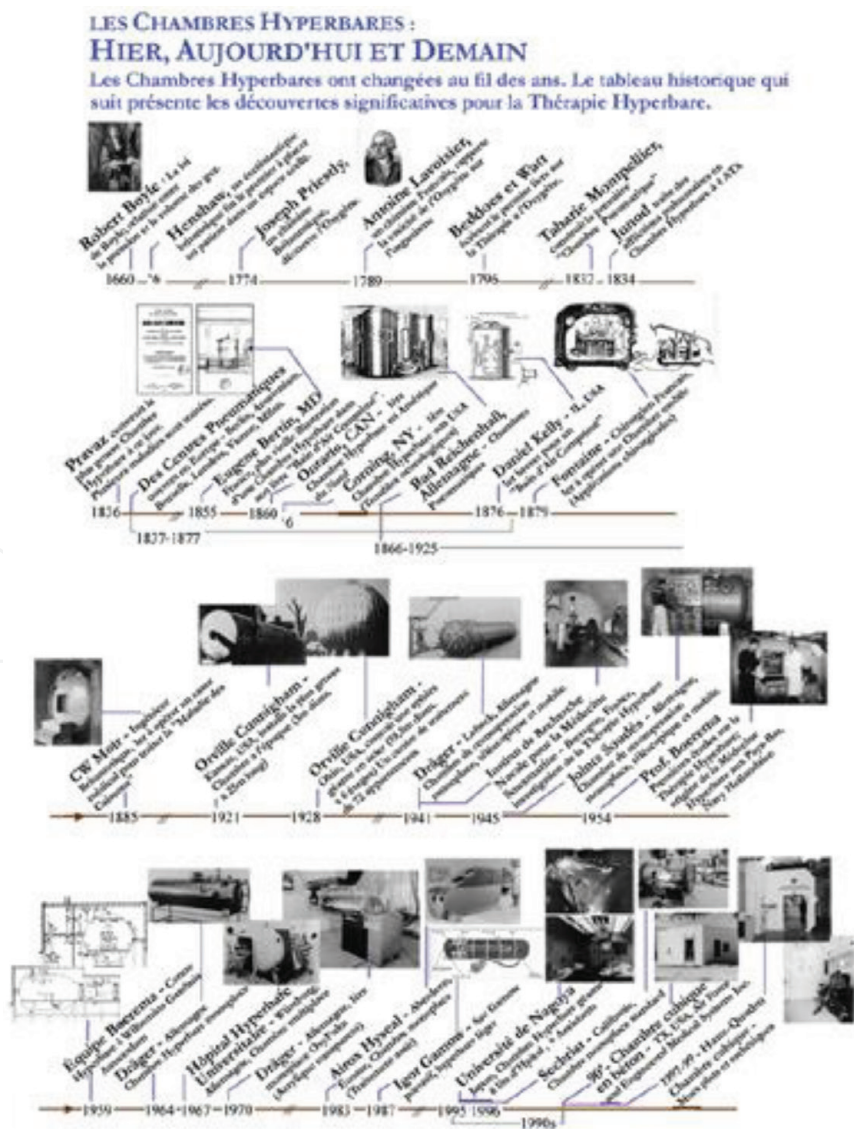


Figure 13.
The evolution of hyperbaric chambers.



Figure 14.
Monoplace HBO chamber.



Figure 15.
Recompression chamber.



Figure 16.
Multiplace HBOT chamber.



Figure 17.
Hyperbaric operation suite.

less expensive. Operating between 1.2 and 1.3 ATA pressures, they are eminently suited for use in homes and spas and also find use to improve results after plastic surgery.

The earliest documentation of therapeutic use of HBOT in animals was in 1998. The Veterinary Hyperbaric Medicine Society was formed in 2006. Veterinary-specific hyperbaric chambers are available.



Figure 18.

Hyperbaric operation suite. (Image courtesy: CONE Health Wound Care and Hyperbaric Center, Greensboro, North Carolina, USA).

The evolution of HBOT chambers over time is chronicled in **Figure 13**.

7. Current status of HBOT

HBOT was called the Cinderella of modern medicine since it was not taught in medical schools and had no pharmaceutical companies to nurture and protect it. Over the course of time, it has shed the label of being a mysterious therapy and become a major tool in the armamentarium of clinicians either as a primary or adjunctive therapy for a spectrum of diseases. Stroke, cancer, heart disease, and chronic lung disease account for almost 60% of the total number of deaths. Hypoxia is a significant component of the pathology of these conditions, and this leads to metabolic acidosis, organ dysfunction, and death. Conventional oxygen therapy may not have desired results, when HBOT yields remarkable clinical improvement. HBOT prevents 75 percent of all major amputations that would otherwise be necessary for diabetic wounds and a 450% increase in complete recovery in patients with traumatic brain injury receiving HBOT vs. standard intensive care. Newer application of HBOT is in emergency care for resuscitation in cases of acute blood loss, near drowning, hanging and poisoning, and cardiorespiratory arrest.

Athletic associations like the NFL employ hyperbaric oxygen therapy as part of the recovery regimen for its athletes, and some players own their own HBOT chambers. Joe Namath experienced remarkable recovery from the head injuries he sustained during his career, leading him to be part of an FDA-approved study of HBOT at the Joe Namath Neurological Center of the Jupiter Medical Center in Florida. Ace swimmer Michael Phelps and football stars Maurice Jones-Drew and James Harrison have endorsed the benefits of HBOT, along with professional boxers like Evander Holyfield [41].

8. Conclusions

With the utilization of isotopic tracers, magnetic resonance imaging (MRI), and single-photon emission computed tomography (SPECT), HBOT is getting evidence-based recognition. Various conditions like brain injuries, stroke, and neurological diseases with poor prognosis are now amenable to improved outcomes with the application of HBOT. There are more than 500 hyperbaric facilities in the USA alone. Much research

remains to be done regarding the efficacy of HBO₂ therapy to develop treatment plans for those in extremes of age. The use of hyperbaric medicine to treat wounds in the foot or in the brain is a divine gift, and great advances in this field are on the horizon. The future of healthcare is here!

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